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Description

BACKGROUND OF THE INVENTION

This invention generally relates to an optical projection system, and specifically relates to an optical projection system for photolithography used in producing integrated circuits, large-scale integrated circuits, or other semiconductor devices.

During the fabrication of semiconductor devices such as integrated circuits, photolithography transfers an image from a photographic mask to a resultant pattern on a semiconductor wafer. Such photolithography generally includes a light exposure process in which a semiconductor wafer is exposed to light having information of a mask pattern. Optical projection systems are used to perform the light exposure process.

In general, transferred mask patterns are very fine so that optical projection systems are required to have a high resolution. The high resolution necessitates a large numerical aperture of the optical projection system and also an essentially null aberration of the optical projection system in the light exposure field. In addition, since a plurality of light exposure steps are sequentially performed to transfer different mask patterns onto a semiconductor wafer in an overlappling manner to complete a composite mask pattern, the optical projection system is required to have a very small distortion.

Japanese published examined patent application 57-12966 discloses an optical projection system using a g-line and i-line light source. This prior-art optical projection system generally requires a large number of thick lenses.

Japanese published unexamined patent application 60-28613 discloses an optical projection system using an excimer laser as a light source. This prior-art optical projection system generally requires a large number of lenses. Furthermore, in this prior-art optical projection system, when an ArF excimer laser is used, the laser light is absorbed by lenses of the system at a high rate.

SUMMARY OF THE INVENTION

It is an object of this invention to provide an excellent optical projection system for photolithography as defined in claims 1 and 4.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a sectional view of an optical projection system according to a first embodiment of this invention.

Fig. 2(a) is a diagram showing the spherical aberration in the optical projection system of Fig. 1.

Fig. 2(b) is a diagram showing the astigmatism in the optical projection system of Fig. 1.

Fig. 2(c) is a diagram showing the distortion in the optical projection system of Fig. 1.

Fig. 3(a) is a diagram showing the meridional transverse aberration in the optical projection system of Fig. 1 which occurs under conditions where an image height is 10.60 mm.

Fig. 3(b) is a diagram showing the sagittal transverse aberration of the optical projection system of Fig. 1 which occurs under conditions where the image height is 10.60 mm.

Fig. 3(c) is a diagram showing the meridional transverse aberration in the optical projection system of Fig. 1 which occurs under conditions where the image height is 0 mm.

Fig. 3(d) is a diagram showing the sagittal transverse aberration of the optical projection system of Fig. 1 which occurs under conditions where the image height is 0 mm.

Fig. 4 is a sectional view of an optical projection system according to a second embodiment of this invention.

Fig. 5(a) is a diagram showing the spherical aberration in the optical projection system of Fig. 4.

Fig. 5(b) is a diagram showing the astigmatism in the optical projection system of Fig. 4.

Fig. 5(c) is a diagram showing the distortion in the optical projection system of Fig. 4.

Fig. 6(a) is a diagram showing the meridional transverse aberration in the optical projection system of Fig. 4 which occurs under conditions where an image height is 10.60 mm.

Fig. 6(b) is a diagram showing the sagittal transverse aberration of the optical projection system of Fig. 4 which occurs under conditions where the image height is 10.60 mm.

Fig. 6(c) is a diagram showing the meridional transverse aberration in the optical projection system of Fig. 4 which occurs under conditions where the image height is 0 mm.

Fig. 6(d) is a diagram showing the sagittal transverse aberration of the optical projection system of Fig. 4 which occurs under conditions where the image height is 0 mm.

Fig. 7 is a diagram showing the relationship between the modulation transfer function and the spatial frequency in the optical projection system of Fig. 4.

Fig. 8 is a sectional view of an optical projection system according to a third embodiment of this invention.

Fig. 9(a) is a diagram showing the spherical aberration in the optical projection system of Fig. 8.

Fig. 9(b) is a diagram showing the astigmatism in the optical projection system of Fig. 8.

Fig. 9(c) is a diagram showing the distortion in the optical projection system of Fig. 8.

Fig. 10(a) is a diagram showing the meridional transverse aberration in the optical projection system of Fig. 8 which occurs under conditions where an image height is 10.60 mm.

Fig. 10(b) is a diagram showing the sagittal transverse aberration of the optical projection system of Fig. 8 which occurs under conditions where the image height is 10.60 mm.

Fig. 10(c) is a diagram showing the meridional transverse aberration in the optical projection system of Fig. 8 which occurs under conditions where the image height is 0 mm.

Fig. 10(d) is a diagram showing the sagittal transverse aberration of the optical projection system of Fig. 8 which occurs under conditions where the image height is 0 mm.

Fig. 11 is a sectional view of an optical projection system according to a fourth embodiment of this invention.

Fig. 12(a) is a diagram showing the spherical aberration in the optical projection system of Fig. 11.

Fig. 12(b) is a diagram showing the astigmatism in the optical projection system of Fig. 11.

Fig. 12(c) is a diagram showing the distortion in the optical projection system of Fig. 11.

Fig. 13(a) is a diagram showing the meridional transverse aberration in the optical projection system of Fig. 11 which occurs under conditions where an image height is 10.60 mm.

Fig. 13(b) is a diagram showing the sagittal transverse aberration of the optical projection system of Fig. 11 which occurs under conditions where the image height is 10.60 mm.

Fig. 13(c) is a diagram showing the meridional transverse aberration in the optical projection system of Fig. 11 which occurs under conditions where the image height is 0 mm.

Fig. 13(d) is a diagram showing the sagittal transverse aberration of the optical projection system of Fig. 11 which occurs under conditions where the image height is 0 mm.

Fig. 14 is a sectional view of an optical projection system according to a fifth embodiment of this invention.

Fig. 15(a) is a diagram showing the spherical aberration in the optical projection system of Fig. 14.

Fig. 15(b) is a diagram showing the astigmatism in the optical projection system of Fig. 14.

Fig. 15(c) is a diagram showing the distortion in the optical projection system of Fig. 14.

Fig. 16(a) is a diagram showing the meridional transverse aberration in the optical projection system of Fig. 14 which occurs under conditions where an image height is 10.60 mm.

Fig. 16(b) is a diagram showing the sagittal transverse aberration of the optical projection system of Fig. 14 which occurs under conditions where the image height is 10.60 mm.

Fig. 16(c) is a diagram showing the meridional transverse aberration in the optical projection system of Fig. 14 which occurs under conditions where the image height is 0 mm.

Fig. 16(d) is a diagram showing the sagittal transverse aberration of the optical projection system of Fig. 14 which occurs under conditions where the image height is 0 mm.

DESCRIPTION OF THE FIRST PREFERRED EMBODIMENT

With reference to Fig. 1, an optical projection system according to a first embodiment of this invention includes a first lens 1, a second lens 2 following the first lens 1, and a third lens 3 following the second lens 2. A group 4 of fourth lenses 4a, 4b, and 4c succeeds the third lens 3. The lens 4a of the group 4 immediately follows the third lens 3. In the group 4, the lens 4a precedes the lens 4b, and the lens 4c follows the lens 4b. Incident rays sequentially pass through the first lens 1, the second lens 2, the third lens 3, and the fourth lens group 4. These lenses 1-4c are supported by known devices (not shown) in such a manner that they have a common optical axis.

The first lens 1 has a negative refracting power. The second lens 2 has a negative refracting power. The third lens 3 has a positive refracting power. The fourth lenses 4a-4c have positive refracting powers. The fourth lens group 4 has a positive refracting power.

It is preferable that at least one of surfaces of the lenses 1-4c is aspherical. It is preferable that the following conditions (1), (2), and (3) are satisfied:

(1) $4f < f3 < 20f$

(2) $0.65 < (f4/d34) < 1.40$

(3) $10f < R5$

where the character "f" denotes a focal length of the optical projection system, the character "f3" denotes a focal length of the third lens 3, the character "f4" denotes a focal length of the fourth lens group 4, the character "d34" denotes a distance between a rear principal point of the third lens 3 and a front principal point of the fourth lens group 4, and the character "R5" denotes a radius of curvature of a front surface of the third lens 3.

Various characters will be introduced to specify the characteristics of the lenses 1-4c and the relationships among the lenses 1-4c. The radii of curvature of the front surface and the rear surface of the first lens 1 are denoted by the characters R1 and R2 respectively. The radii of curvature of the front surface and the rear surface of the second lens 2 are denoted by the characters R3 and R4 respectively. The radii of curvature of the front surface and the rear surface of the third lens 3 are denoted by the characters R5 and R6 respectively. The radii of curvature of the front surface and the rear surface of the lens 4a are denoted by the characters R7 and R8 respectively. The radii of curvature of the front surface and the rear surface of the lens 4b are denoted by the characters R9 and R10 respectively. The radii of curvature of the front surface and the rear surface of the lens 4c are denoted by the characters R11 and R12 respectively.

The thickness of the first lens 1 is denoted by the character d1. The thickness of the second lens 2 is denoted by the character d3. The thickness of the third lens 3 is denoted by the character d5. The thickness of the lens 4a is denoted by the character d7. The thickness of the lens 4b is denoted by the character d9. The thickness of the lens 4c is denoted by the character d11. It should be noted that the lens thicknesses d1, d3, d5, d7, d9, and d11 are measured along the optical axis.

The distance between the rear surface of the first lens 1 and the front surface of the second lens 2 is denoted by the character d2. The distance between the rear surface of the second lens 2 and the front surface of the third lens 3 is denoted by the character d4. The distance between the rear surface of the third lens 3 and the front surface of the lens 4a is denoted by the character d6. The distance between the rear surface of the lens 4a and the front surface of the lens 4b is denoted by the character d8. The distance between the rear surface of the lens 4b and the front surface of the lens 4c is denoted by the character d10. It should be noted that these distances d2, d4, d6, d8, and d10 are measured along the optical axis.

The refractive indexes of glass material of the lenses 1, 2, 3, 4a, 4b, and 4c are denoted by the characters n1, n2, n3, n4, n5, and n6 respectively. These refractive indexes n1-n6 are determined with respect to light having a wavelength of 193 nm.

In one example of the optical projection system of this embodiment, the lenses 1, 2, 3, 4a, 4b, and 4c are designed so that the previously-mentioned lens parameters have the following values.

R1 = -573.75000	d1 = 200.00	n1 = 1.560769
R2 = 591.4613	d2 = 813.129	
R3 = -329.1979*	d3 = 90.687	n2 = 1.560769
R4 = -666.4207	d4 = 555.124	
R5 = 2262.686*	d5 = 140.741	n3 = 1.560769
R6 = -1193.422	d6 = 57.632	
R7 = 856.7510	d7 = 153.836	n4 = 1.560769
R8 = -7183.481	d8 = 333.031	
R9 = 754.1443	d9 = 129.443	n5 = 1.560769
R10 = -5310.126	d10 = 125.81	
R11 = 347.1155	d11 = 149.823	n6 = 1.560769
R12 = 538.1785*		
where the character "*" denotes that the related surface is aspherical, and the radii R1-R12 and the thicknesses and the distances d1-d11 are represented in unit of mm.		

The aspherical surfaces (R3, R5, and R12) of the lenses 2, 3, and 4c are designed as follows. In general, the characteristics of an aspherical surface are defined in the following known equation.

$$Z(h) = [(h^2/R)/\{1 + \sqrt{1 - (1 + K)h^2/R^2}\}] + Ah^4 + Bh^6 + Ch^8 + Dh^{10} \quad (1)$$

where the character Z(h) denotes a sag quantity; the character "h" denotes a distance from the optical axis; the character R denotes a radius of curvature; the character K denotes a conic coefficient; and the characters A, B, C, and D denote aspherical surface coefficients.

In respect of the aspherical surface (R3) of the lens 2, the coefficients K and A-D are chosen as follows.

R3:	K = -0.03608	A = 2.014E-10 C = 4.023E-20	B = -2.302E-15 D = 2.721E-24
where the character E denotes an exponential, and "E-N" means that the value which precedes "E-N" is multiplied by 10^{-N}.			

In respect of the aspherical surface (R5) of the lens 3, the coefficients K and A-D are chosen as follows.

R5:	K = 5.661	A = -8.343E-10 C = 2.187E-21	B = 2.499E-16 D = -3.910E-23

In respect of the aspherical surface (R12) of the lens 4c, the coefficients K and A-D are chosen as follows.

R12:	K = 1.810	A = 1.213E-9 C = 4.809E-18	B = -2.094E-14 D = -9.969E-23

The previously-mentioned example of the optical projection system has the following characteristics. Under conditions where light having a wavelength λ of 193 nm is used and an image height Y is 10.60 mm: the focal length "f" of the optical projection system is 100 mm; the numerical aperture N.A. of the optical projection system is 0.45; the magnification of the optical projection system is 1/5; the focal length f3 of the third lens 3 is 1382.40 mm; and the ratio "f4/d34" between the focal length f4 of the fourth lens group 4 and the distance d34 between the rear principal point of the third lens 3 and the front principal point of the fourth lens group 4 is 1.129.

Fig. 2(a), Fig. 2(b), and Fig. 2(c) show the spherical aberration, the astigmatism, and the distortion of the previously-mentioned example of the optical projection system respectively.

Fig. 3(a) and Fig. 3(b) show the meridional transverse aberration and the sagittal transverse aberration of the previously-mentioned example of the optical projection system respectively under conditions where the image height Y is 10.60 mm. Fig. 3(c) and Fig. 3(d) show the meridional transverse aberration and the sagittal transverse aberration of the previously-mentioned example of the optical projection system respectively under conditions where the image height Y is 0 mm.

The first lens 1 and the second lens 2 function to perform a correction which moves Petzval's sum to a value near zero. The third lens 3 and the fourth lens group 4 are designed to form a dioptric Schmidt optical system which corrects the coma and the spherical aberration of the optical projection system. These corrective arrangements and the provision of at least one aspherical lens surface ensure that the optical projection system can be essentially free from aberrations and can be composed of a small number of lenses. In addition, the optical projection system absorbs light at a lower rate than that in the prior art systems.

DESCRIPTION OF THE SECOND PREFERRED EMBODIMENT

Fig. 4 shows a second embodiment of this invention which is similar to the embodiment of Figs. 1-3 except for the following design changes. The embodiment of Fig. 4 additionally includes a fifth lens 5 which succeeds a fourth lens group 4. The fifth lens 5 has a common optical axis with lenses 1-3 and the fourth lens group 4. The fifth lens 5 has a negative refracting power.

The radii of curvature of the front surface and the rear surface of the fifth lens 5 are denoted by the characters R13 and R14. The distance between the rear surface of a lens 4c and the front surface of the fifth lens 5 which is measured along the optical axis is denoted by the character d12. The thickness of the fifth lens 5 which is measured along the optical axis is denoted by the character d13. With respect to light having a wavelength of 193 nm, the refractive index of glass material of the fifth lens 5 is denoted by the character n7.

In one example of the optical projection system of this embodiment, the lenses 1, 2, 3, 4a, 4b, 4c, and 5 are designed so that their lens parameters have the following values.

R1 = 361.1966*	d1 = 17.861	n1 = 1.560769
R2 = 149.2153	d2 = 429.297	
R3 = -2254.465*	d3 = 16.824	n2 = 1.560769
R4 = 489.8852	d4 = 247.598	
R5 = 2993.532*	d5 = 52.384	n3 = 1.560769
R6 = -564.7170	d6 = 21.052	
R7 = 1029.028	d7 = 64.766	n4 = 1.560769
R8 = -632.4123	d8 = 283.667	
R9 = 280.7900	d9 = 48.378	n5 = 1.560769
R10 = 920.3827	d10 = 46.114	
R11 = 174.9364	d11 = 45.734	n6 = 1.560769
R12 = 348.2636*	d12 = 124.315	
R13 = -254.2200*	d13 = 16.855	n7 = 1.560769
R14 = -2140.726		
where the character "*" denotes that the related surface is aspherical, and the radii R1-R14 and the thicknesses and the distances d1-d14 are represented in unit of mm.		

The aspherical surfaces (R1, R3, R5, R12, and R13) of the lenses 1, 2, 3, 4c, and 5 are designed as follows. As described previously, the characteristics of an aspherical surface are defined in the equation (1).

In respect of the aspherical surface (R1) of the lens 1, the coefficients K and A-D are chosen as follows.

R1:	K = -5.946	A = 4.194E-8 C = -1.844E-16	B = 2.179E-13 D = 3.136E-20
where the character E denotes an exponential, and "E-N" means that the value which precedes "E-N" is multiplied by 10^{-N}.			

In respect of the aspherical surface (R3) of the lens 2, the coefficients K and A-D are chosen as follows.

R3:	K = -369.862	A = -1.603E-8 C = -4.502E-18	B = 2.167E-13 D = 2.483E-22

In respect of the aspherical surface (R5) of the lens 3, the coefficients K and A-D are chosen as follows.

R5:	K = 29.473	A = -1.310E-9 C = 2.489E-20	B = -7.525E-15 D = -2.782E-25

In respect of the aspherical surface (R12) of the lens 4c, the coefficients K and A-D are chosen as follows.

R12:	K = 0.0327	A = -1.065E-9 C = 8.755E-19	B = -1.233E-13 D = 1.161E-23

In respect of the aspherical surface (R13) of the lens 5, the coefficients K and A-D are chosen as follows.

R13:	K = -62.855	A = -7.389E-7 C = -2.209E-14	B = 2.930E-10 D = -6.476E-17

Under conditions where light having a wavelength λ of 193 nm is used and an image height Y is 10.60 mm: the focal length "f" of the optical projection system is 100 mm; the numerical apertúre N.A. of the optical projection system is 0.45; the magnification of the optical projection system is 1/5; the focal length f3

of the third lens 3 is 851.722 mm; and the ratio "f4/d34" between the focal length f4 of the fourth lens group 4 and the distance d34 between the rear principal point of the third lens 3 and the front principal point of the fourth lens group 4 is 0.882.

Fig. 5(a), Fig. 5(b), and Fig. 5(c) show the spherical aberration, the astigmatism, and the distortion of the optical projection system respectively.

Fig. 6(a) and Fig. 6(b) show the meridional transverse aberration and the sagittal transverse aberration of the optical projection system respectively under conditions where the image height Y is 10.60 mm. Fig. 6(c) and Fig. 6(d) show the meridional transverse aberration and the sagittal transverse aberration of the optical projection system respectively under conditions where the image height Y is 0 mm.

Fig. 7 shows the relationship between the modulation transfer function (MTF) and the spatial frequency of the projection optical system under conditions where the image height Y is 10.60 mm and the image height Y is 0 mm.

DESCRIPTION OF THE THIRD PREFERRED EMBODIMENT

Fig. 8 shows a third embodiment of this invention which is similar to the embodiment of Figs. 4-7 except for the following design changes.

In the embodiment of Fig. 8, lenses 1, 2, 3, 4a, 4b, 4c, and 5 are designed so that their lens parameters have the following values.

R1 = 505.350*	d1 = 3.000	n1 = 1.560769
R2 = 165.000	d2 = 521.550	
R3 = -2176.430*	d3 = 3.0000	n2 = 1.560769
R4 = 479.6000	d4 = 247.377	
R5 = 2477.590*	d5 = 50.0000	n3 = 1.560769
R6 = -526.1900	d6 = 11.522	
R7 = 1345.960	d7 = 50.000	n4 = 1.560769
R8 = -613.4500	d8 = 356.208	
R9 = 294.2700	d9 = 30.000	n5 = 1.560769
R10 = 1232.070	d10 = 30.020	
R11 = 193.4100	d11 = 22.000	n6 = 1.560769
R12 = 352.1500*	d12 = 161.144	
R13 = -160.7380*	d13 = 3.0000	n7 = 1.560769
R14 = -301.6440		
where the character "*" denotes that the related surface is aspherical, and the radii R1-R14 and the thicknesses and the distances d1-d14 are represented in unit of mm.		

The aspherical surfaces (R1, R3, R5, R12, and R13) of the lenses 1, 2, 3, 4c, and 5 are designed as follows. As described previously, the characteristics of an aspherical surface are defined in the equation (1).

In respect of the aspherical surface (R1) of the lens 1, the coefficients K and A-D are chosen as follows.

R1:	K = -0.302	A = 2.593E-8 C = -2.140E-16	B = 3.952E-13 D = 3.756E-20
where the character E denotes an exponential, and "E-N" means that the value which precedes "E-N" is multiplied by 10^{-N}.			

In respect of the aspherical surface (R3) of the lens 2, the coefficients K and A-D are chosen as follows.

R3:	K = -184.400	A = -1.541E-8 C = -2.926E-19	B = 7.278E-14 D = 6.444E-23

In respect of the aspherical surface (R5) of the lens 3, the coefficients K and A-D are chosen as follows.

R5:	K = 41.240	A = -1.168E-9 C = 2.090E-20	B = -6.467E-15 D = -1.210E-25

In respect of the aspherical surface (R12) of the lens 4c, the coefficients K and A-D are chosen as follows.

R12:	K = 0.0290	A = -1.084E-9 C = -3.170E-19	B = -3.270E-14 D = 2.105E-24

In respect of the aspherical surface (R13) of the lens 5, the coefficients K and A-D are chosen as follows.

R13:	K = -16.008	A = -5.892E-7 C = -2.210E-14	B = 2.437E-10 D = -6.476E-17

Under conditions where light having a wavelength λ of 193 nm is used and an image height Y is 10.60 mm: the focal length "f" of the optical projection system is 100 mm; the numerical aperture N.A. of the optical projection system is 0.45; the magnification of the optical projection system is 1/5; the focal length f3 of the third lens 3 is 778.620 mm; and the ratio "f4/d34" between the focal length f4 of the fourth lens group 4 and the distance d34 between the rear principal point of the third lens 3 and the front principal point of the fourth lens group 4 is 0.867.

Fig. 9(a), Fig. 9(b), and Fig. 9(c) show the spherical aberration, the astigmatism, and the distortion of the optical projection system respectively.

Fig. 10(a) and Fig. 10(b) show the meridional transverse aberration and the sagittal transverse aberration of the optical projection system respectively under conditions where the image height Y is 10.60 mm. Fig. 10(c) and Fig. 10(d) show the meridional transverse aberration and the sagittal transverse aberration of the optical projection system respectively under conditions where the image height Y is 0 mm.

DESCRIPTION OF THE FOURTH PREFERRED EMBODIMENT

Fig. 11 shows a fourth embodiment of this invention which is similar to the embodiment of Figs. 4-7 except for the following design changes.

In the embodiment of Fig. 11, lenses 1, 2, 3, 4a, 4b, 4c, and 5 are designed so that their lens parameters have the following values.

R1 = 4480.716*	d1 = 57.718	n1 = 1.560769
R2 = 454.077	d2 = 386.334	
R3 = -4709.995*	d3 = 22.256	n2 = 1.560769
R4 = 1649.148	d4 = 296.127	
R5 = 2547.206*	d5 = 26.707	n3 = 1.560769
R6 = -661.2696	d6 = 180.065	
R7 = 590.0694	d7 = 53.909	n4 = 1.560769
R8 = -1050.142	d8 = 16.682	
R9 = 273.9922	d9 = 39.849	n5 = 1.560769
R10 = 892.8735	d10 = 4.125	
R11 = 128.7190	d11 = 53.888	n6 = 1.560769
R12 = 232.1479*	d12 = 113.451	
R13 = -190.5371*	d13 = 13.384	n7 = 1.560769
R14 = 429.5090		
where the character "*" denotes that the related surface is aspherical, and the radii R1-R14 and the thicknesses and the distances d1-d14 are represented in unit of mm.		

The aspherical surfaces (R1, R3, R5, R12, and R13) of the lenses 1, 2, 3, 4c, and 5 are designed as follows. As described previously, the characteristics of an aspherical surface are defined in the equation (1).

In respect of the aspherical surface (R1) of the lens 1, the coefficients K and A-D are chosen as follows.

R1:	K = -109.360	A = 1.387E-8 C = 8.326E-17	B = -1.549E-12 D = -1.882E-20
where the character E denotes an exponential, and "E-N" means that the value which precedes "E-N" is multiplied by 10^{-N}.			

In respect of the aspherical surface (R3) of the lens 2, the coefficients K and A-D are chosen as follows.

R3:	K = -3933.68	A = -2.565E-8 C = -7.972E-18	B = 3.056E-13 D = 3.337E-22

In respect of the aspherical surface (R5) of the lens 3, the coefficients K and A-D are chosen as follows.

R5:	K = 3.993	A = -1.415E-9 C = -5.048E-19	B = -5.250E-14 D = -1.293E-23

In respect of the aspherical surface (R12) of the lens 4c, the coefficients K and A-D are chosen as follows.

R12:	K = -0.00887	A = -1.399E-9 C = -2.368E-19	B = -3.901E-13 D = 1.441E-22

In respect of the aspherical surface (R13) of the lens 5, the coefficients K and A-D are chosen as follows.

R13:	K = 5.798	A = -8.440E-7 C = -2.209E-14	B = 5.184E-10 D = -6.476E-17

Under conditions where light having a wavelength λ of 193 nm is used and an image height Y is 10.60 mm: the focal length "f" of the optical projection system is 100 mm; the numerical aperture N.A. of the optical projection system is 0.45; the magnification of the optical projection system is 1/5; the focal length f3 of the third lens 3 is 905.876 mm; and the ratio "f4/d34" between the focal length f4 of the fourth lens group 4 and the distance d34 between the rear principal point of the third lens 3 and the front principal point of the fourth lens group 4 is 0.907.

Fig. 12(a), Fig. 12(b), and Fig. 12(c) show the spherical aberration, the astigmatism, and the distortion of the optical projection system respectively.

Fig. 13(a) and Fig. 13(b) show the meridional transverse aberration and the sagittal transverse aberration of the optical projection system respectively under conditions where the image height Y is 10.60 mm. Fig. 13(c) and Fig. 13(d) show the meridional transverse aberration and the sagittal transverse aberration of the optical projection system respectively under conditions where the image height Y is 0 mm.

DESCRIPTION OF THE FIFTH PREFERRED EMBODIMENT

Fig. 14 shows a fifth embodiment of this invention which is similar to the embodiment of Figs. 4-7 except for the following design changes.

In the embodiment of Fig. 14, lenses 1, 2, 3, 4a, 4b, 4c, and 5 are designed so that their lens parameters have the following values.

R1 = -647.0977	d1 = 200.00	n1 = 1.560769
R2 = 545.1320	d2 = 821.1736	
R3 = -333.2931*	d3 = 86.586	n2 = 1.560769
R4 = -715.0375	d4 = 549.439	
R5 = 2243.695*	d5 = 143.590	n3 = 1.560769
R6 = -1201.589	d6 = 66.666	
R7 = 855.2784	d7 = 149.058	n4 = 1.560769
R8 = -7031.113	d8 = 330.014	
R9 = 758.2768	d9 = 120.777	n5 = 1.560769
R10 = -5024.299	d10 = 126.382	
R11 = 352.3274	d11 = 152.195	n6 = 1.560769
R12 = 547.6737*	d12 = 58.639	
R13 = 389366.05*	d13 = 0.0004	n7 = 1.560769
R14 = 80504.838		
where the character "*" denotes that the related surface is aspherical, and the radii R1-R14 and the thicknesses and the distances d1-d14 are represented in unit of mm.		

The aspherical surfaces (R3, R5, R12, and R13) of the lenses 2, 3, 4c, and 5 are designed as follows. As described previously, the characteristics of an aspherical surface are defined in the equation (1).

In respect of the aspherical surface (R3) of the lens 2, the coefficients K and A-D are chosen as follows.

R3:	K = -0.05174 ,	A = 2.681E-10 C = 5.872E-20	B = -8.178E-16 D = 2.065E-24
where the character E denotes an exponential, and "E-N" means that the value which precedes "E-N" is multiplied by 10^{-N}.			

In respect of the aspherical surface (R5) of the lens 3, the coefficients K and A-D are chosen as follows.

R5:	K = 5.8542	A = -8.318E-10 C = -2.343E-21	B = 2.365E-16 D = -2.984E-27

In respect of the aspherical surface (R12) of the lens 4c, the coefficients K and A-D are chosen as follows.

R12:	K = 1.6202	A = 1.038E-9 C = 3.064E-18	B = -1.150E-14 D = 9.213E-23

In respect of the aspherical surface (R13) of the lens 5, the coefficients K and A-D are chosen as follows.

R13:	K = 0.0000	A = -1.434E-10 C = 2.288E-17	B = -1.001E-10 D = -2.529E-30

Under conditions where light having a wavelength λ of 193 nm is used and an image height Y is 10.60 mm: the focal length "f" of the optical projection system is 100 mm; the numerical aperture N.A. of the optical projection system is 0.45; the magnification of the optical projection system is 1/5; the focal length f3 of the third lens 3 is 1416.653 mm; and the ratio "f4/d34" between the focal length f4 of the fourth lens group 4 and the distance d34 between the rear principal point of the third lens 3 and the front principal point of the fourth lens group 4 is 1.125.

Fig. 15(a), Fig. 15(b), and Fig. 15(c) show the spherical aberration, the astigmatism, and the distortion of the optical projection system respectively.

Fig. 16(a) and Fig. 16(b) show the meridional transverse aberration and the sagittal transverse aberration of the optical projection system respectively under conditions where the image height Y is 10.60 mm. Fig. 16(c) and Fig. 16(d) show the meridional transverse aberration and the sagittal transverse aberration of the optical projection system respectively under conditions where the image height Y is 0 mm.

Claims

1. An optical projection system for photolithography comprising:
   a first lens (1), a second lens (2), and a third lens (3) arranged successively in a direction of travel of a ray, the first lens (1) having a predetermined negative refracting power, the second lens (2) having a predetermined negative refracting power, the third lens (3) having a predetermined positive refracting power;
   a group of fourth lenses (4) which follows the third lens (3) in the direction of travel of the ray and which has a predetermined positive refracting power;
   wherein at least one of the surfaces of the first (1), second (2), third (3), and fourth lenses (4a, 4b, 4c) is aspherical, and wherein the following conditions (1), (2), and (3) are satisfied:
   (1) $4f < f3 < 20f$
   (2) $0.65 < (f4/d34) < 1.40$
   (3) $10f < R5$
   where the character "f" denotes a focal length of the optical projection system, the character "f3" denotes a focal length of the third lens (3), the character "f4" denotes a focal length of the fourth lens group (4), the character "d34" denotes a distance between a rear principal point of the third lens (3) and a front principal point of the fourth lens group (4), and the character "R5" denotes a radius of curvature of a front surface of the third lens (3).

2. The optical projection system of claim 1 wherein the front surface of the third lens (3) is aspherical.

3. The optical projection system of claim 1 wherein each of the fourth lenses (4a, 4b, 4c) has a predetermined positive refracting power.

4. An optical projection system for photolithography comprising:
   a first lens (1), a second lens (2), and a third lens (3) arranged successively in a direction of travel of a ray, the first lens (1) having a predetermined negative refracting power, the second lens (2) having a predetermined negative refracting power, the third lens (3) having a predetermined positive refracting power;
   a group of fourth lenses (4) which follows the third lens (3) in the direction of travel of the ray and which has a predetermined positive refracting power;
   a fifth lens (5) following the fourth lens group (4) in the direction of travel of the ray and having a predetermined negative refracting power;
   wherein at least one of the surfaces of the first (1), second (2), third (3), fourth lenses (4a, 4b, 4c), and fifth lenses (5) is aspherical, and wherein the following conditions (1), (2), and (3) are satisfied:
   (1) $4f < f3 < 20f$
   (2) $0.65 < (f4/d34) < 1.40$
   (3) $10f < R5$
   where the character "f" denotes a focal length of the optical projection system, the character "f3" denotes a focal length of the third lens (3), the character "f4" denotes a focal length of the fourth lens group (4), the character "d34" denotes a distance between a rear principal point of the third lens (3) and a front principal point of the fourth lens group (4), and the character "R5" denotes a radius of curvature of a front surface of the third lens.

5. The optical projection system of claim 4 wherein the front surface of the third lens (3) is aspherical.

6. The optical projection system of claim 4 wherein each of the fourth lenses (4a, 4b, 4c) has a predetermined positive refracting power.

Patentansprüche

1. Optisches Projektionssystem für Photolithographie mit
   einer ersten Linse (1), einer zweiten Linse (2) und einer dritten Linse (3), die nacheinander in der Bewegungsrichtung eines Strahls angeordnet sind, wobei die erste Linse (1) einen vorbestimmten negativen Brechwert hat, die zweite Linse (2) einen vorbestimmten negativen Brechwert hat und die dritte Linse (3) einen vorbestimmten positiven Brechwert hat,
   einer Gruppe vierter Linsen (4), die in der Bewegungsrichtung des Strahls auf die dritte Linse (3) folgt und einen vorbestimmten positiven Brechwert hat,
   wobei mindestens eine der Flächen der ersten Linse (1), der zweiten Linse (2), der dritten Linse (3) und der vierten Linsen (4a, 4b, 4c) nichtsphärisch ist, und die folgenden Bedingungen (1), (2) und (3) erfüllt sind
   (1) $4f < f3 < 20f$
   (2) $0,65 < (f4/d34) < 1,40$
   (3) $10f < R5$
   wobei das Zeichen "f" die Brennweite des optischen Projektionssystems, das Zeichen "f3" die Brennweite der dritten Linse (3), das Zeichen "f4" die Brennweite der Gruppe der vierten Linsen (4), das Zeichen "d34" den Abstand zwischen dem rückseitigen Hauptpunkt der dritten Linse (3) und dem vorderen Hauptpunkt der Gruppe der vierten Linsen (4) und das Zeichen "R5" den Krümmungsradius der vorderen Oberfläche der dritten Linse (3) bezeichnet.

2. Optisches Projektionssystem nach Anspruch 1, wobei die vordere Oberfläche der dritten Linse (3) nichtsphärisch ist.

3. Optisches Projektionssystem nach Anspruch 1, wobei jede der vierten Linsen (4a, 4b, 4c) einen vorbestimmten positiven Brechwert hat.

4. Optisches Projektionssystem für Photolithographie mit
   einer ersten Linse (1), einer zweiten Linse (2) und einer dritten Linse (3), die nacheinander in der Bewegungsrichtung eines Strahls angeordnet sind, wobei die erste Linse (1) einen vorbestimmten negativen Brechwert hat, die zweite Linse (2) einen vorbestimmten negativen Brechwert hat und die dritte Linse (3) einen vorbestimmten positiven Brechwert hat,
   einer Gruppe vierter Linsen (4), die in der Bewegungsrichtung des Strahls auf die dritte Linse (3) folgt und einen vorbestimmten positiven Brechwert hat,
   einer fünften Linse (5), die in der Bewegungsrichtung des Strahls auf die Gruppe der vierten Linsen (4) folgt und einen vorbestimmten negativen Brechwert hat,
   wobei mindestens eine der Flächen der ersten Linse (1), der zweiten Linse (2), der dritten Linse (3), der vierten Linsen (4a, 4b, 4c) und der fünften Linse (5) nichtsphärisch ist, und die folgenden Bedingungen (1), (2) und (3) erfüllt sind
   (1) $4f < f3 < 20f$
   (2) $0,65 < (f4/d34) < 1,40$
   (3) $10f < R5$
   wobei das Zeichen "f" die Brennweite des optischen Projektionssystems, das Zeichen "f3" die Brennweite der dritten Linse (3), das Zeichen "f4" die Brennweite der Gruppe der vierten Linsen (4), das Zeichen "d34" den Abstand zwischen dem rückseitigen Hauptpunkt der dritten Linse (3) und dem vorderen Hauptpunkt der Gruppe der vierten Linsen (4) und das Zeichen "R5" den Krümmungsradius der vorderen Oberfläche der dritten Linse bezeichnet.

5. Optisches Projektionssystem nach Anspruch 4, wobei die vordere Oberfläche der dritten Linse (3) nichtsphärisch ist.

6. Optisches Projektionssystem nach Anspruch 4, wobei jede der vierten Linsen (4a, 4b, 4c) einen vorbestimmten positiven Brechwert hat.

Revendications

1. Système de projection optique pour la photolithographie qui comprend :

- une première lentille (1), une seconde lentille (2) et une troisième lentille (3) disposées les unes derrière les autres dans la direction de déplacement d'un rayon lumineux, la première lentille (1) ayant un pouvoir réfringent négatif prédéterminé, la seconde lentille (2) ayant un pouvoir réfringent négatif prédéterminé, la troisième lentille (3) ayant un pouvoir réfringent positif prédéterminé,
- un groupe de quatrièmes lentilles (4) situé après la troisième lentille (3) dans la direction de déplacement du rayon lumineux et ayant un pouvoir réfringent positif prédéterminé,

dans lequel l'une au moins des surfaces des première (1), seconde (2), troisième (3) et quatrièmes lentilles (4a, 4b, 4c) est asphérique, et dans lequel les conditions (1), (2) et (3) suivantes sont satisfaites :

(1) $4f < f3 < 20f$
(2) $0,65 < (f4/d34) < 1,40$
(3) $10f < R5$

dans lesquelles le symbole "f" désigne la longueur focale du système de projection optique, le symbole "f3" désigne la longueur focale de la troisième lentille (3), le symbole "f4" désigne la longueur focale du groupe de quatrièmes lentilles (4), le symbole "d34" désigne la distance entre le point arrière principal de la troisième lentille (3) et le point avant principal du groupe de quatrièmes lentilles (4) et le symbole "R5" désigne le rayon de courbure de la surface avant de la troisième lentille (3).

2. Système de projection optique selon la revendication 1, dans lequel la surface avant de la troisième lentille (3) est asphérique.

3. Système de projection optique selon la revendication 1, dans lequel chacune des quatrièmes lentilles (4a, 4b, 4c) a un pouvoir réfringent positif prédéterminé.

4. Système de projection optique pour la photolithographie qui comprend :
   - une première lentille (1), une seconde lentille (2) et une troisième lentille (3) disposées les unes derrière les autres dans la direction de déplacement d'un rayon lumineux, la première lentille (1) ayant un pouvoir réfringent négatif prédéterminé, la seconde lentille (2) ayant un pouvoir réfringent négatif prédéterminé, la troisième lentille (3) ayant un pouvoir réfringent positif prédéterminé,
   - un groupe de quatrièmes lentilles (4) situé après la troisième lentille (3) dans la direction de déplacement du rayon lumineux et ayant un pouvoir réfringent positif prédéterminé,
   - une cinquième lentille (5) qui suit le groupe de quatrièmes lentilles (4) dans la direction de déplacement du rayon lumineux et qui a un pouvoir réfringent négatif prédéterminé,

   dans lequel l'une au moins des surfaces des première (1), seconde (2), troisième (3), quatrièmes (4a, 4b, 4c) et cinquième lentilles est asphérique, et dans lequel les conditions (1), (2) et (3) suivantes sont satisfaites :

   (1) $4f < f3 < 20f$
   (2) $0,65 < (f4/d34) < 1,40$
   (3) $10f < R5$

   dans lesquelles le symbole "f" désigne la longueur focale du système de projection optique, le symbole "f3" désigne la longueur focale de la troisième lentille (3), le symbole "f4" désigne la longueur focale du groupe de quatrièmes lentilles (4) le symbole "d34" désigne la distance entre le point arrière principal de la troisième lentille (3) et le point avant principal du groupe de quatrièmes lentilles (4) et le symbole "R5" désignent le rayon de courbure de la surface avant de la troisième lentille (3).

5. Système de projection optique selon la revendication 4, dans lequel la surface avant de la troisième lentille (3) est asphérique.

6. Système de projection optique selon la revendication 4, dans lequel chacune des quatrièmes lentilles (4a, 4b, 4c) a un pouvoir réfringent positif prédéterminé.

FIG. 1

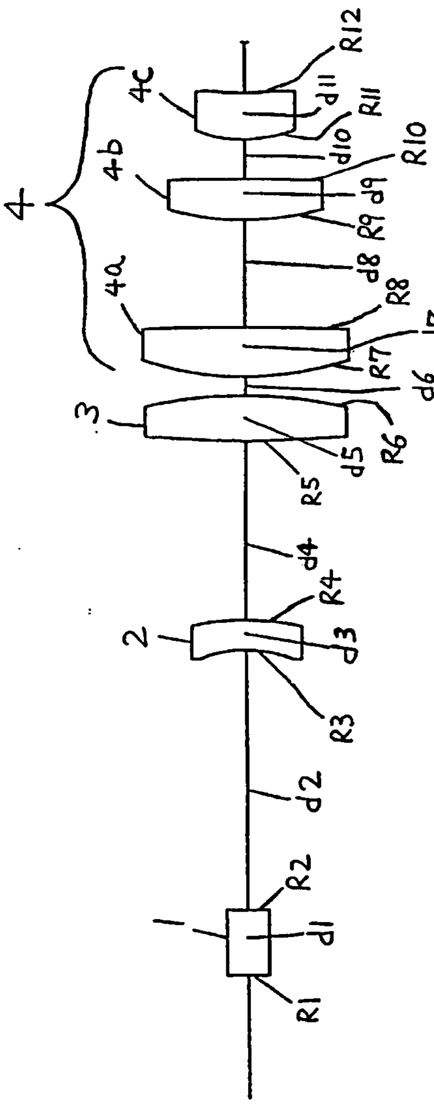

1
2
3
4
4a
4b
4c
R1
R2
R3
R4
R5
R6
R7
R8
R9
R10
R11
R12
d1
d2
d3
d4
d5
d6
d7
d8
d9
d10
d11

FIG. 2

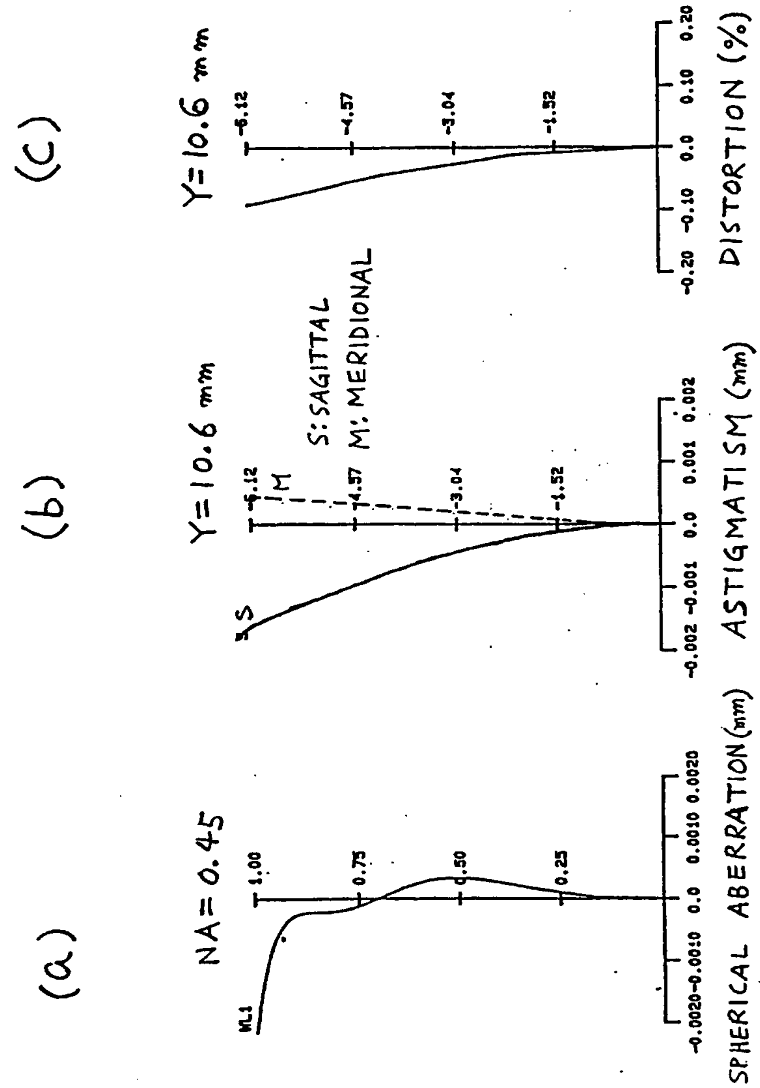
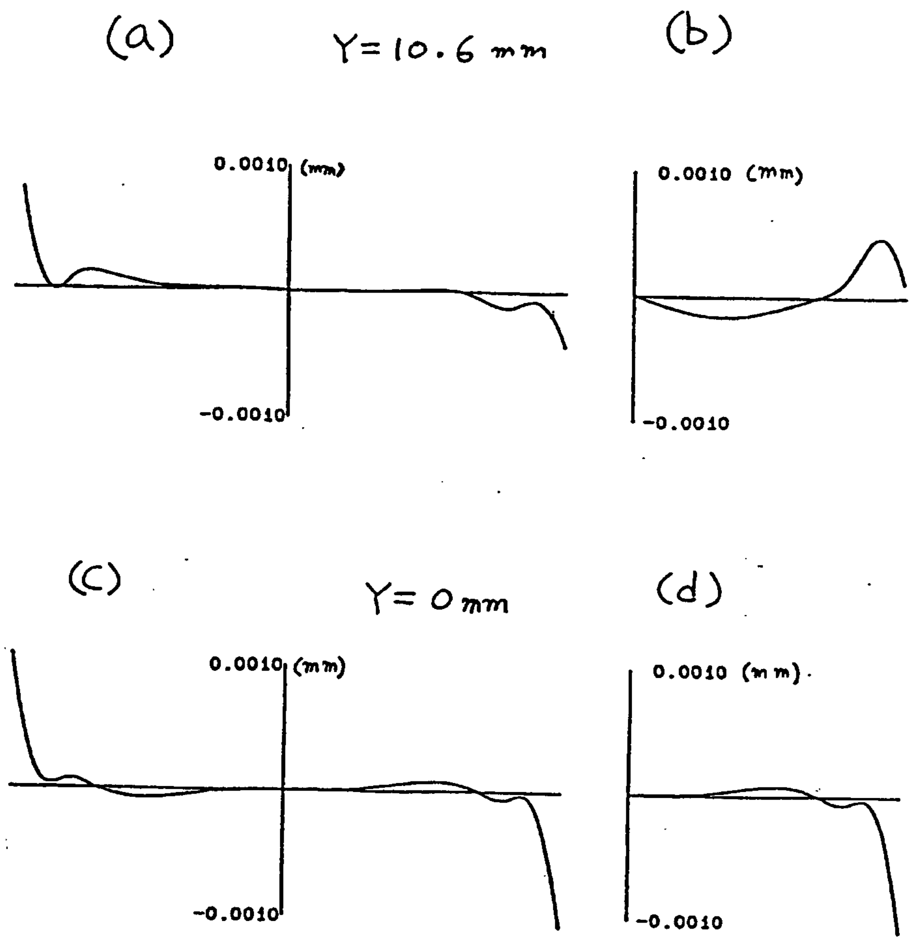

(a)
NA = 0.45
SPHERICAL ABERRATION (mm)
(b)
Y = 10.6 mm
S: SAGITTAL
M: MERIDIONAL
ASTIGMATISM (mm)
(c)
Y = 10.6 mm
DISTORTION (%)

FIG. 3


(a)
Y=10.6 mm
(b)
0.0010 (mm)
-0.0010
0.0010 (mm)
-0.0010
(c)
Y= 0 mm
(d)
0.0010 (mm)
-0.0010
0.0010 (mm)
-0.0010

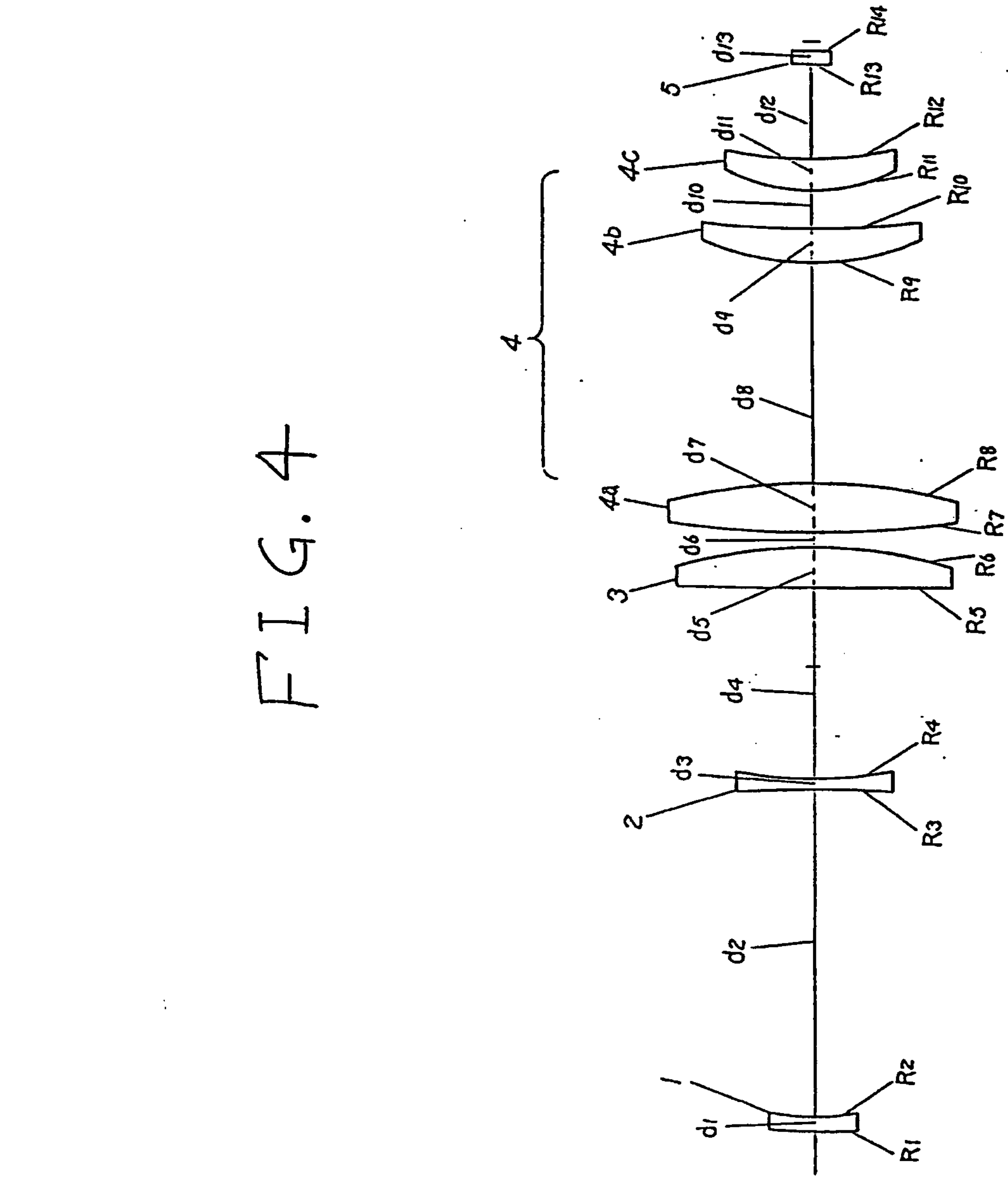

1
2
3
4
4a
4b
4C
5
d1
d2
d3
d4
d5
d6
d7
d8
d9
d10
d11
d12
d13
R1
R2
R3
R4
R5
R6
R7
R8
R9
R10
R11
R12
R13
R14

FIG. 4

FIG. 5

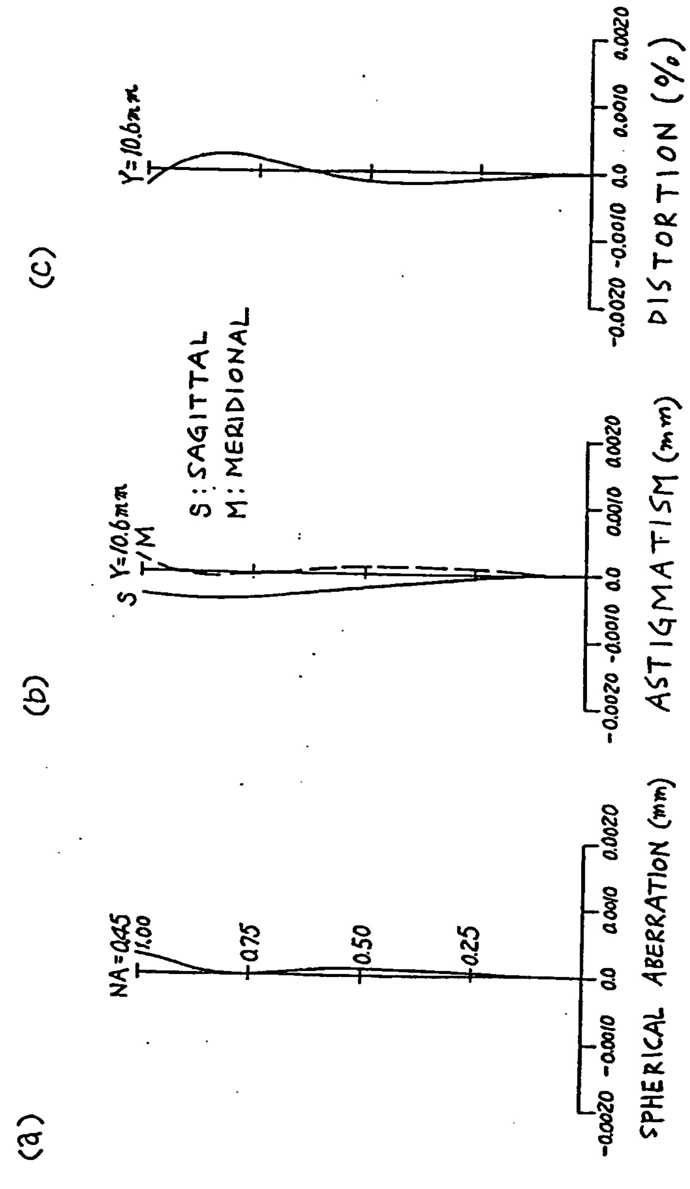

(a)
NA=0.45
1.00
0.75
0.50
0.25
-0.0020 -0.0010 0.0 0.0010 0.0020
SPHERICAL ABERRATION (mm)
(b)
S Y=10.6mm
M
S: SAGITTAL
M: MERIDIONAL
-0.0020 -0.0010 0.0 0.0010 0.0020
ASTIGMATISM (mm)
(c)
Y=10.6mm
-0.0020 -0.0010 0.0 0.0010 0.0020
DISTORTION (%)

FIG. 6

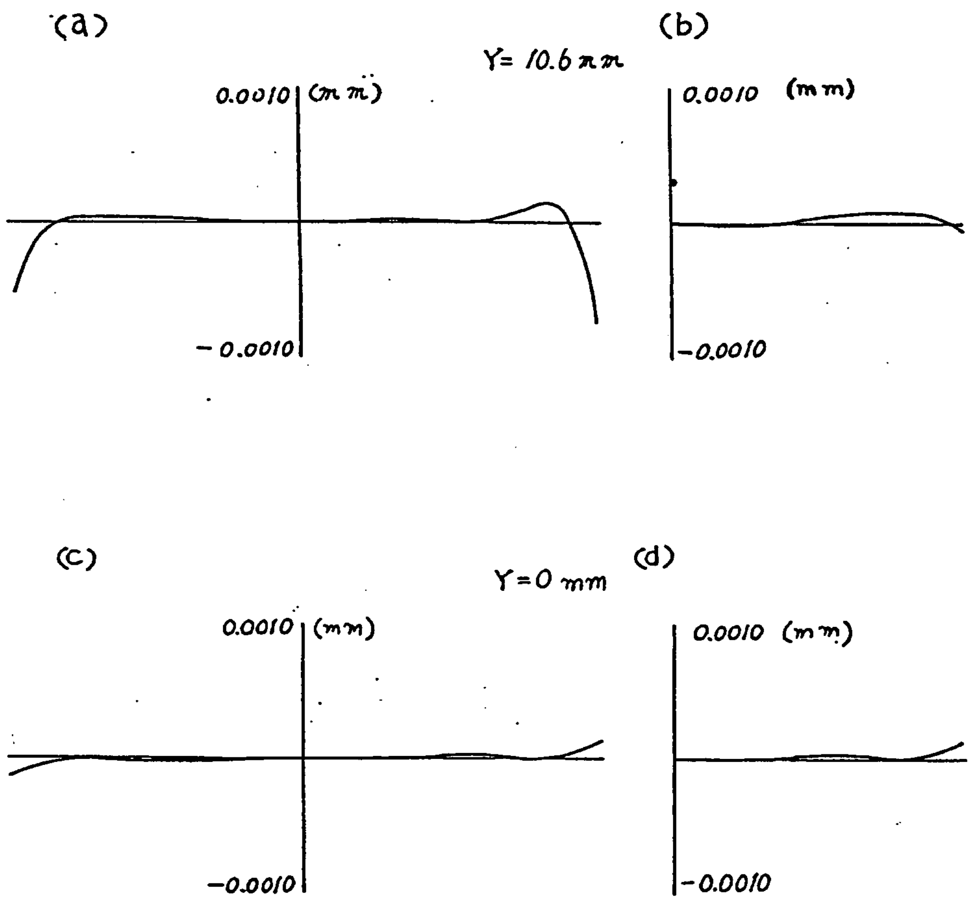
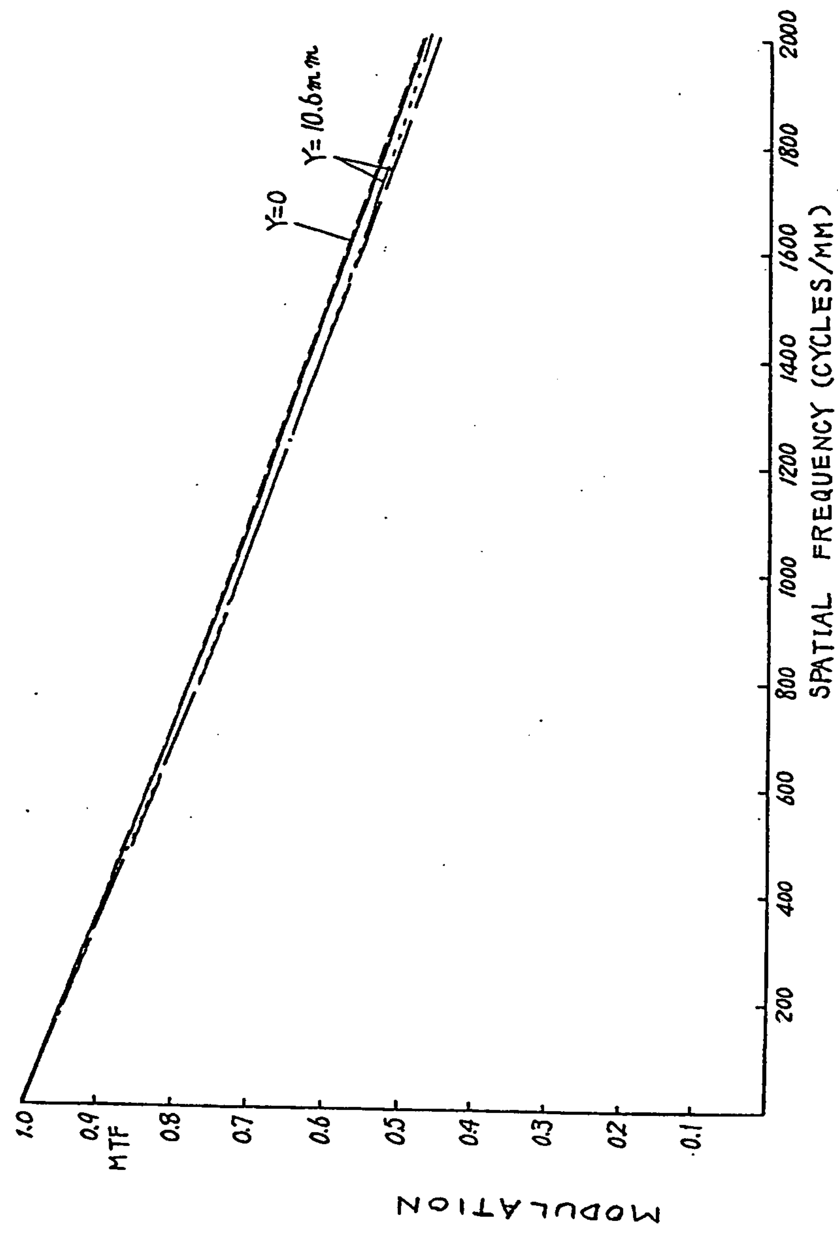

(a)
(b)
Y= 10.6 mm
0.0010 (mm)
− 0.0010
0.0010 (mm)
−0.0010
(c)
(d)
Y=0 mm
0.0010 (mm)
−0.0010
0.0010 (mm)
− 0.0010

FIG. 7



Y=0
Y=10.6mm
1.0
0.9
MTF
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
MODULATION
200
400
600
800
1000
1200
1400
1600
1800
2000
SPATIAL FREQUENCY (CYCLES/MM)

FIG. 8

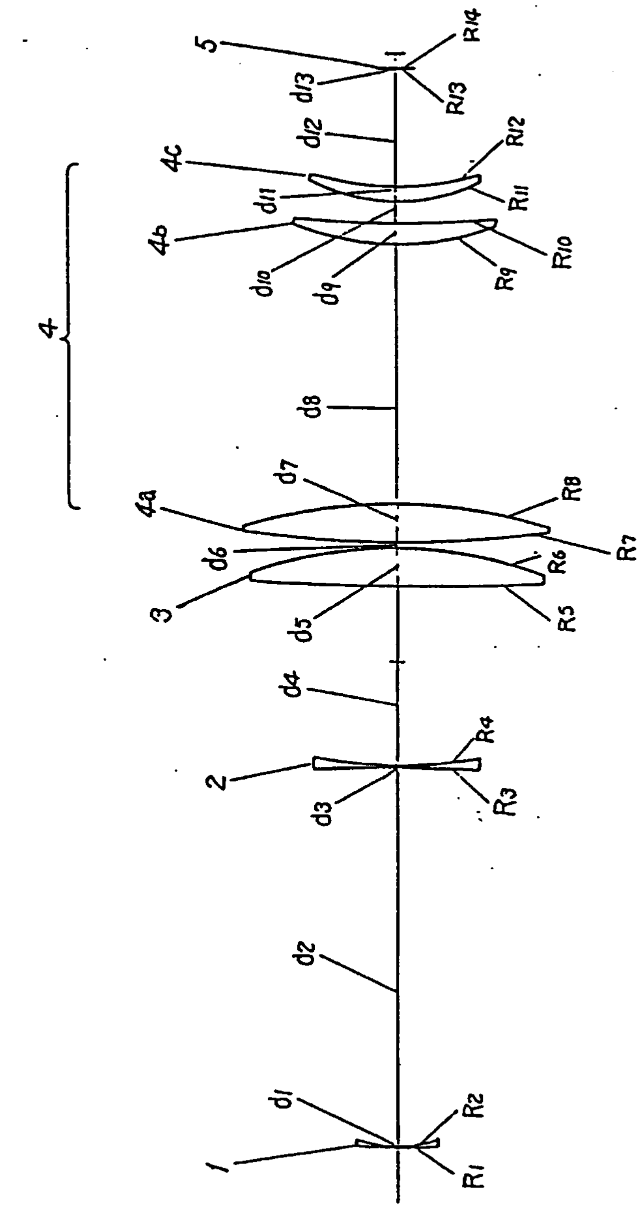

1
2
3
4
4a
4b
4c
5
d1
d2
d3
d4
d5
d6
d7
d8
d9
d10
d11
d12
d13
R1
R2
R3
R4
R5
R6
R7
R8
R9
R10
R11
R12
R13
R14

FIG. 9

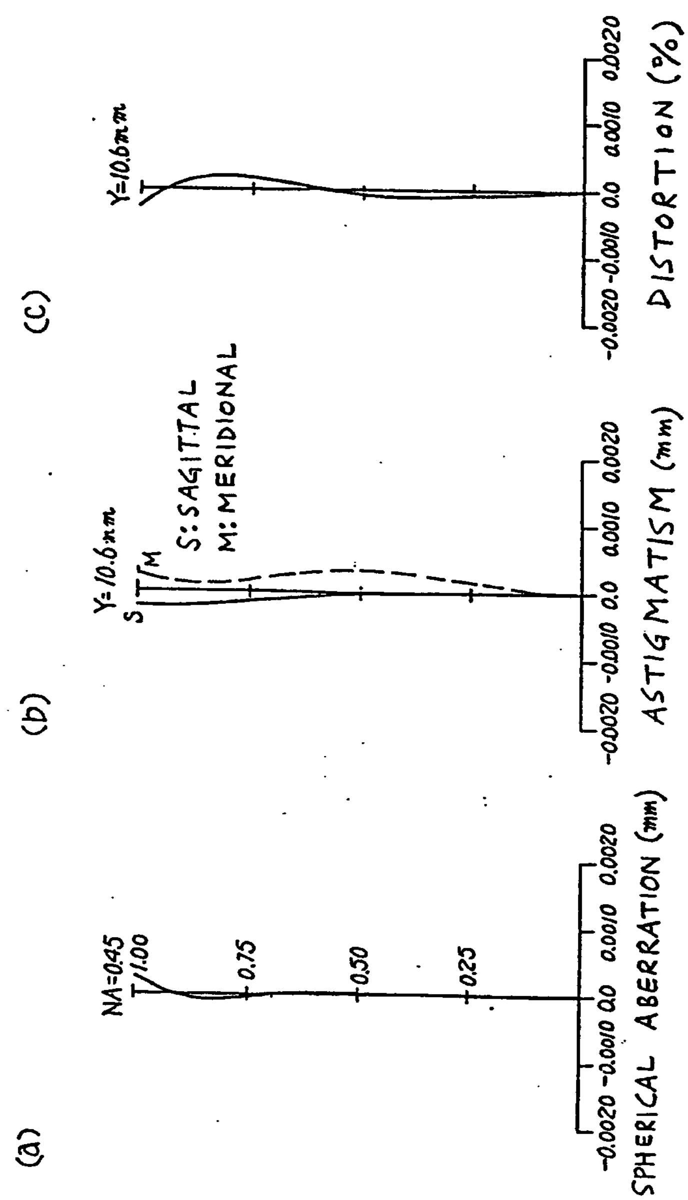

(a)
NA=0.45
1.00
0.75
0.50
0.25
-0.0020 -0.0010 0.0 0.0010 0.0020
SPHERICAL ABERRATION (mm)
(b)
Y=10.6mm
S
T
M
S: SAGITTAL
M: MERIDIONAL
-0.0020 -0.0010 0.0 0.0010 0.0020
ASTIGMATISM (mm)
(C)
Y=10.6mm
-0.0020 -0.0010 0.0 0.0010 0.0020
DISTORTION (%)

FIG. 10

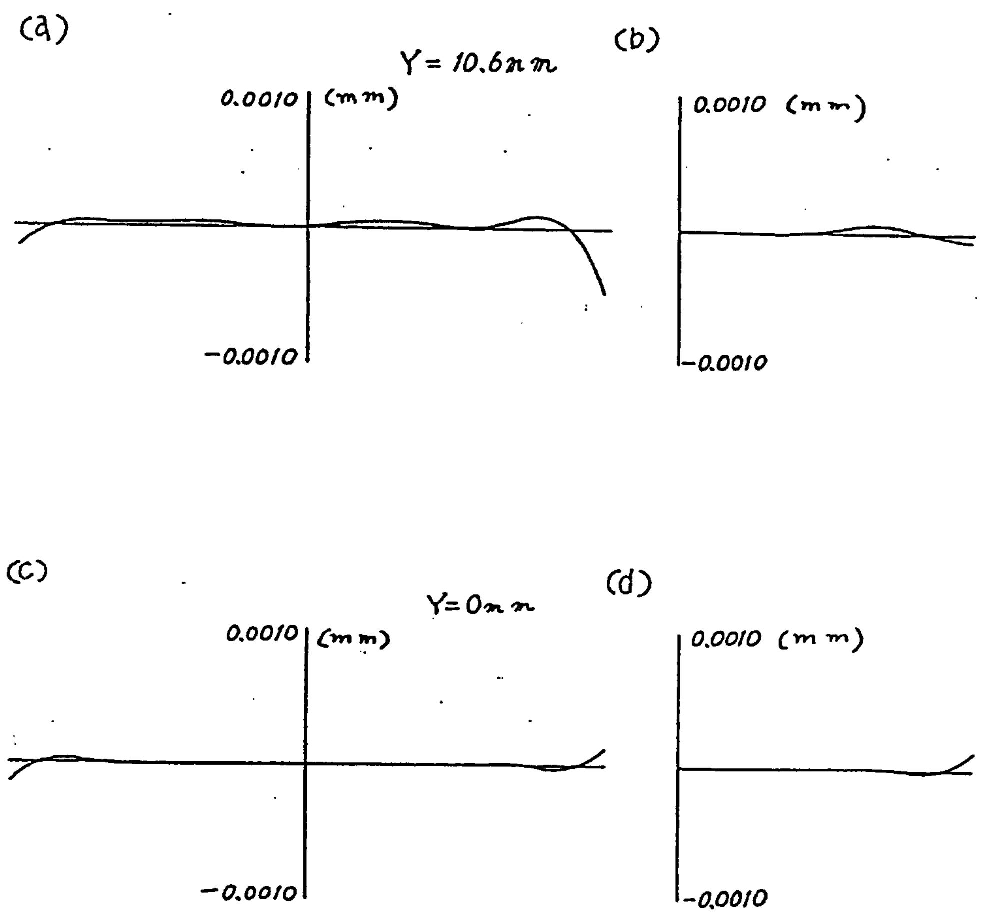

(a)
Y = 10.6mm
0.0010 (mm)
-0.0010
(b)
0.0010 (mm)
-0.0010
(c)
Y= 0mm
0.0010 (mm)
-0.0010
(d)
0.0010 (mm)
-0.0010

FIG. 11

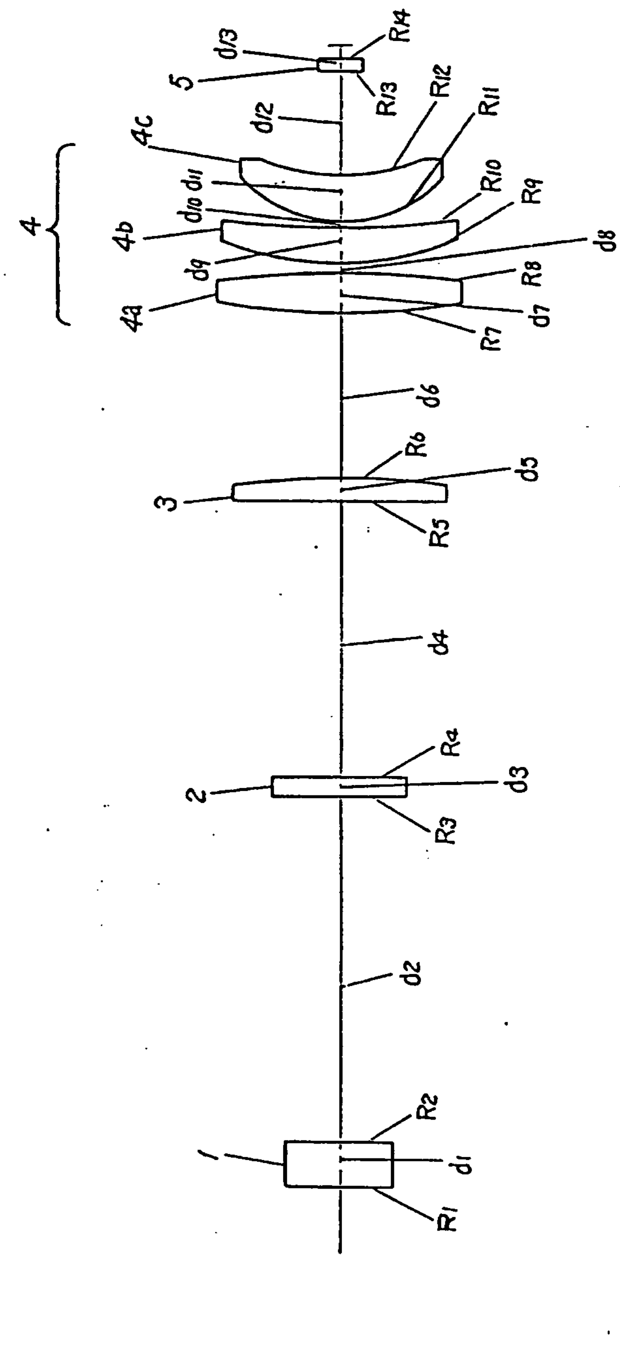

1
2
3
4
4a
4b
4c
5
R1
R2
R3
R4
R5
R6
R7
R8
R9
R10
R11
R12
R13
R14
d1
d2
d3
d4
d5
d6
d7
d8
d9
d10
d11
d12
d13

FIG. 12

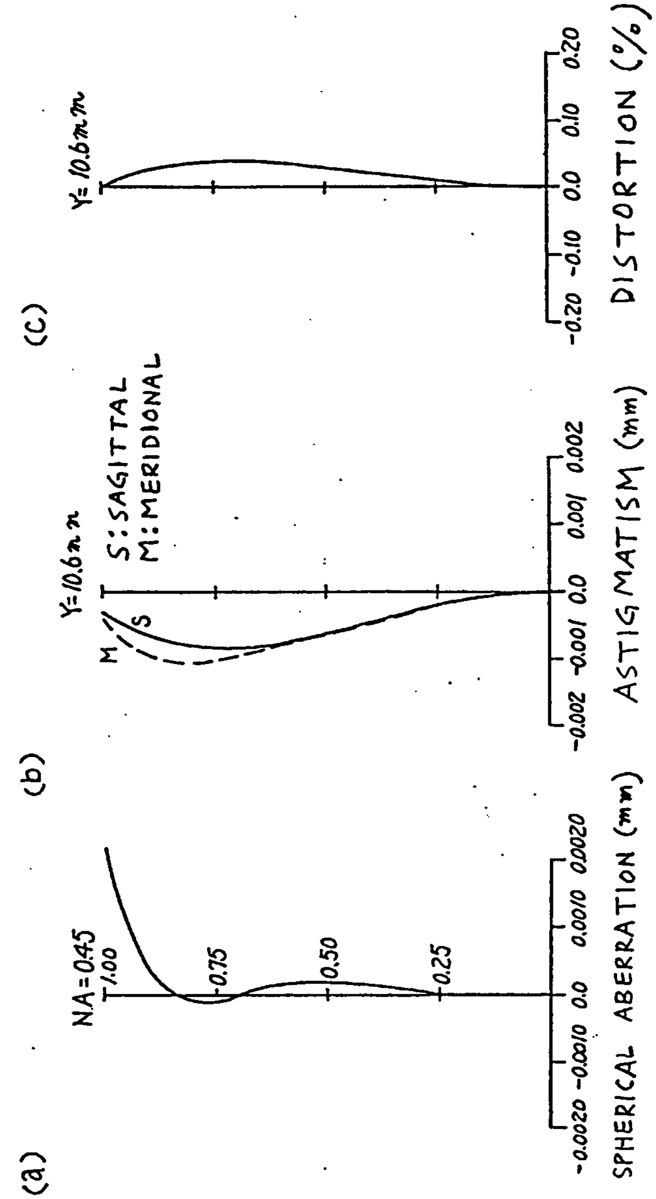
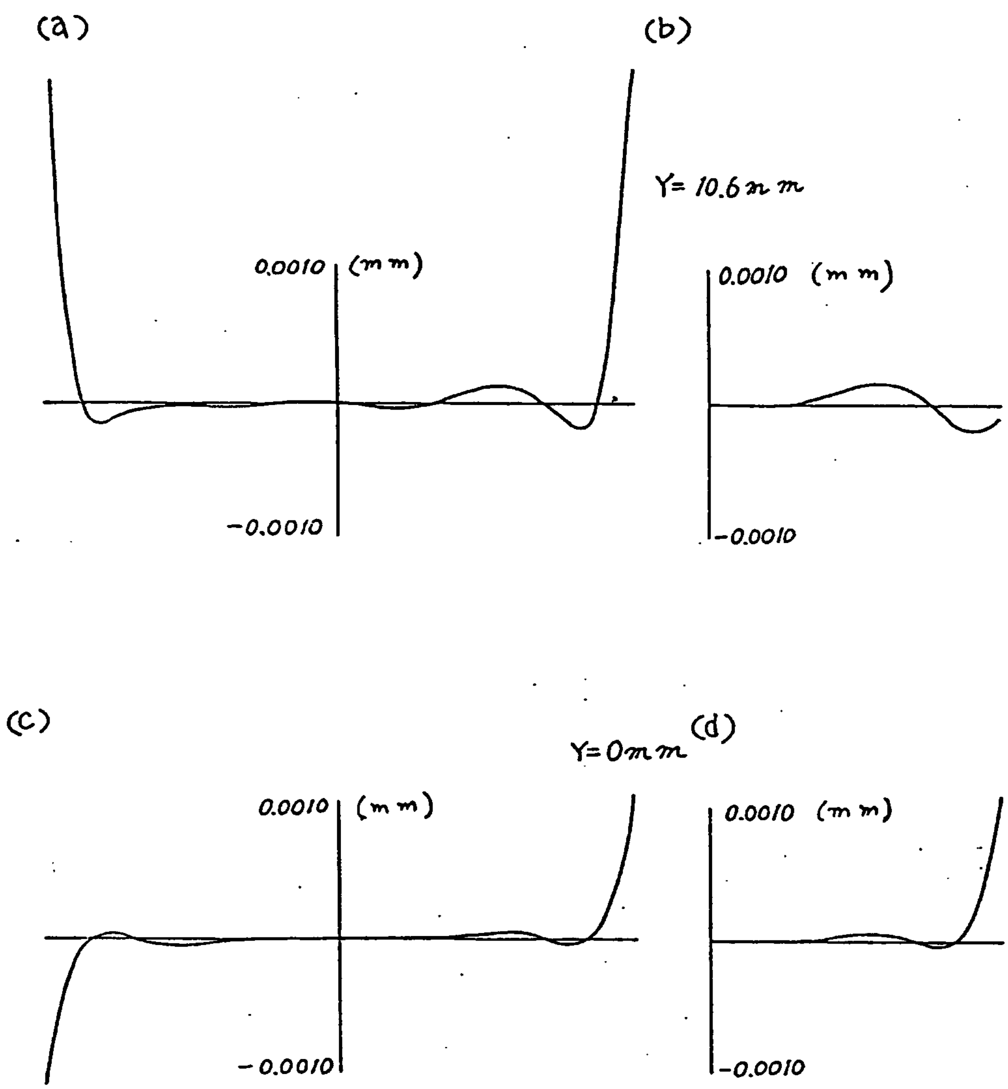

(a)
NA=0.45
1.00
0.75
0.50
0.25
-0.0020 -0.0010 0.0 0.0010 0.0020
SPHERICAL ABERRATION (mm)
(b)
Y=10.6mm
S: SAGITTAL
M: MERIDIONAL
M
S
-0.002 -0.001 0.0 0.001 0.002
ASTIGMATISM (mm)
(c)
Y=10.6mm
-0.20 -0.10 0.0 0.10 0.20
DISTORTION (%)

FIG. 13


(a)
(b)
Y= 10.6 mm
0.0010
(mm)
-0.0010
0.0010
(mm)
-0.0010
(c)
(d)
Y= 0mm
0.0010
(mm)
- 0.0010
0.0010
(mm)
-0.0010

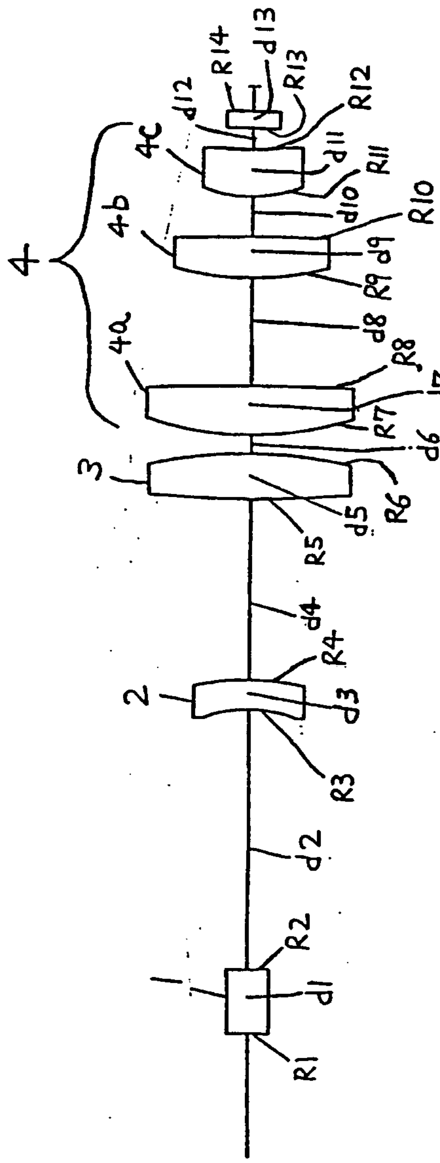

1
R1
d1
R2
d2
2
R3
d3
R4
d4
3
R5
d5
R6
d6
4
4a
R7
d7
R8
d8
4b
R9
d9
R10
d10
4c
R11
d11
R12
d12
R13
d13
R14

FIG. 14

FIG. 15

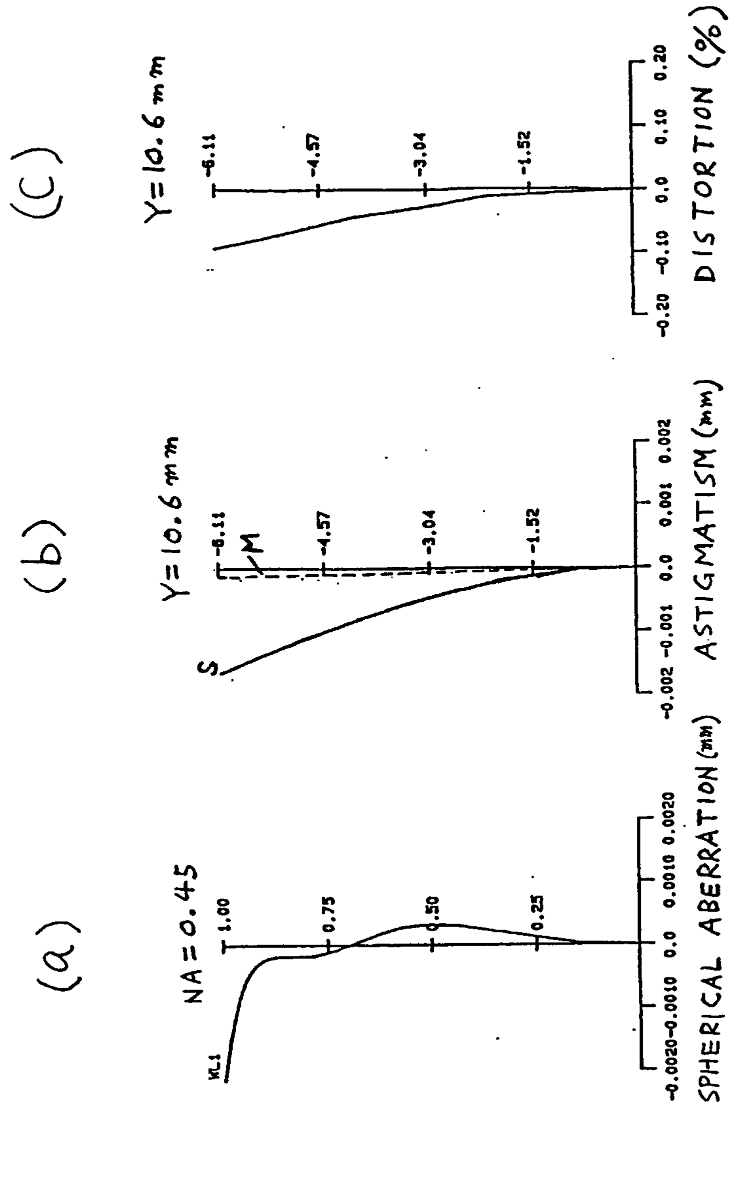
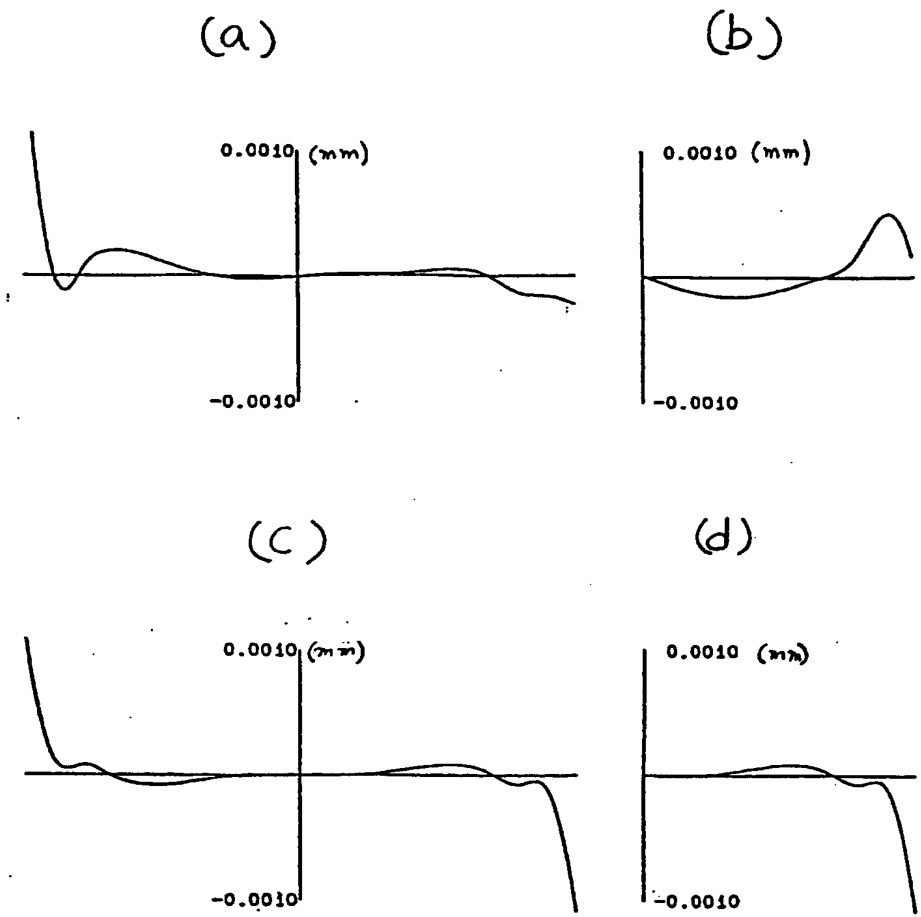

(a)
NA = 0.45
1.00
0.75
0.50
0.25
-0.0020 -0.0010 0.0 0.0010 0.0020
SPHERICAL ABERRATION (mm)
(b)
Y = 10.6 mm
S
M
-6.11
-4.57
-3.04
-1.52
-0.002 -0.001 0.0 0.001 0.002
ASTIGMATISM (mm)
(c)
Y = 10.6 mm
-6.11
-4.57
-3.04
-1.52
-0.20 -0.10 0.0 0.10 0.20
DISTORTION (%)

FIG. 16


(a)
(b)
0.0010 (mm)
-0.0010
0.0010 (mm)
-0.0010
(c)
(d)
0.0010 (mm)
-0.0010
0.0010 (mm)
-0.0010